The DarkSide-20k TPC and Underground Argon Cryogenic System

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for the DarkSide Collaboration

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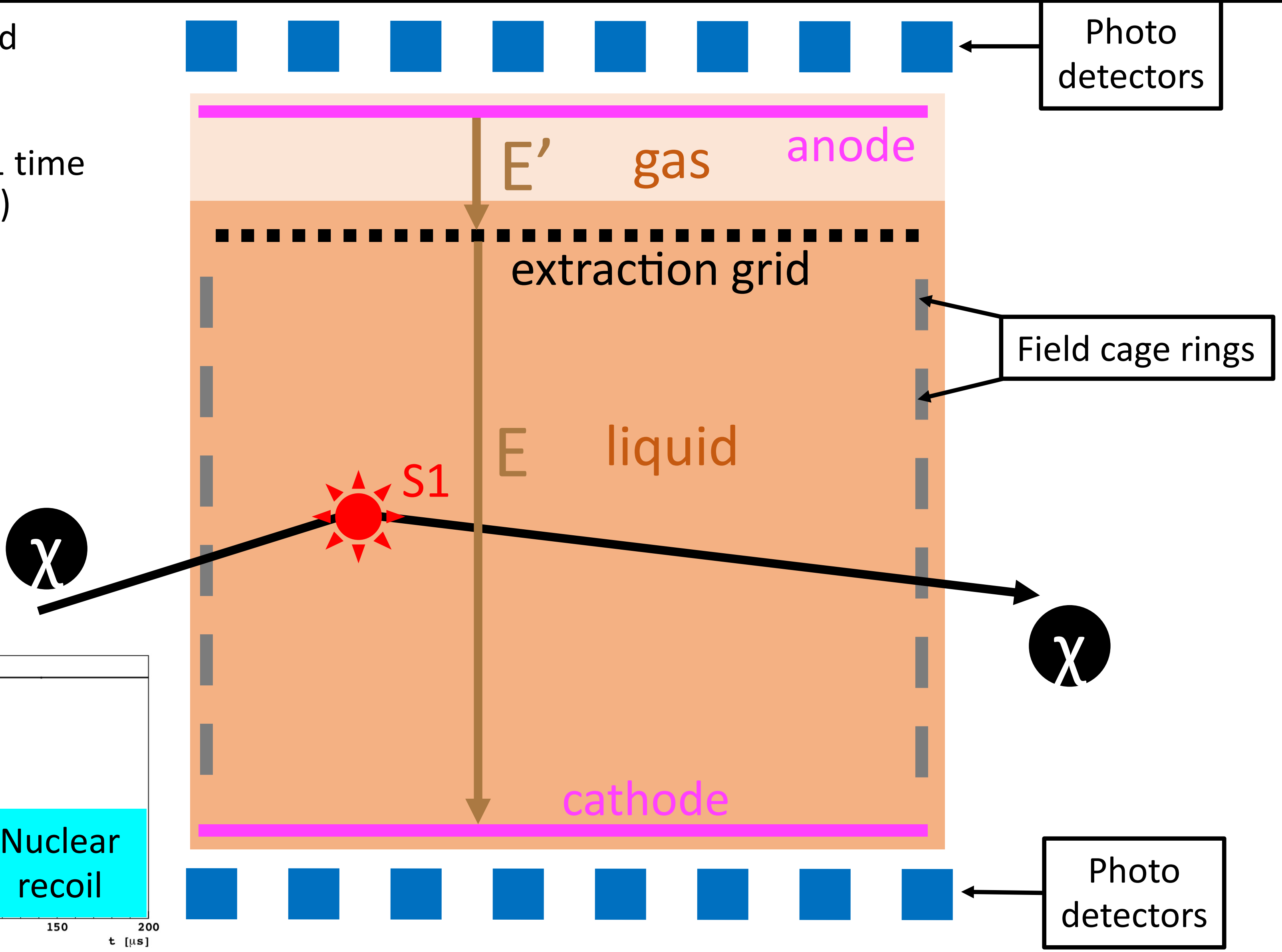
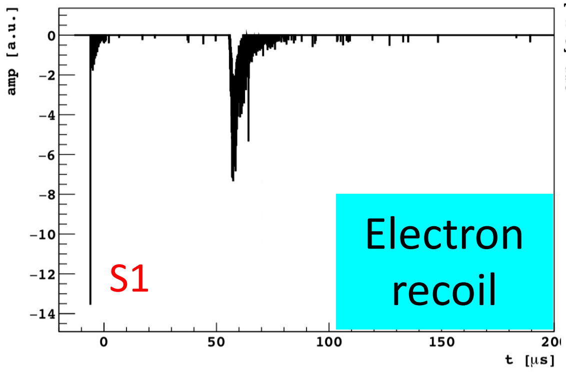
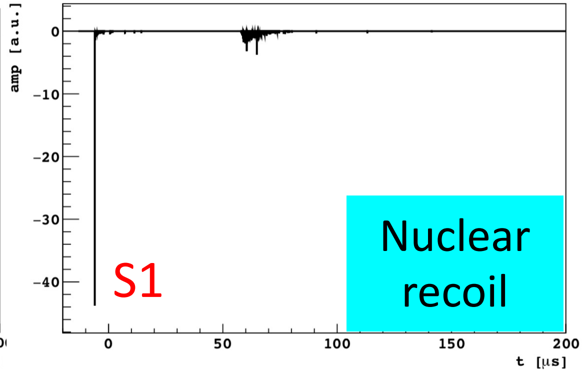
Dual-Phase Argon Time Projection Chamber (TPC)

- Small gas pocket maintained above the liquid
- Higher electric field across gas pocket
- Electron recoil discrimination exploits the S1 time signature – Pulse Shape Discrimination (PSD)







Dual-Phase Argon Time Projection Chamber (TPC)

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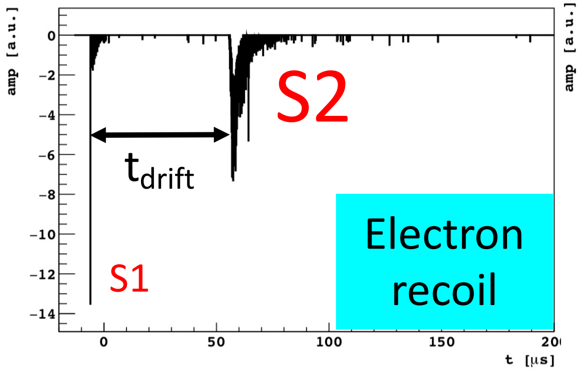
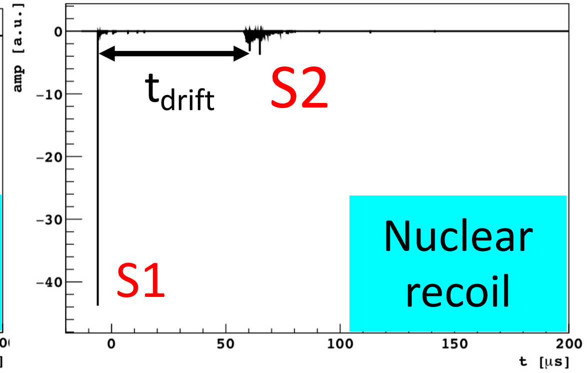
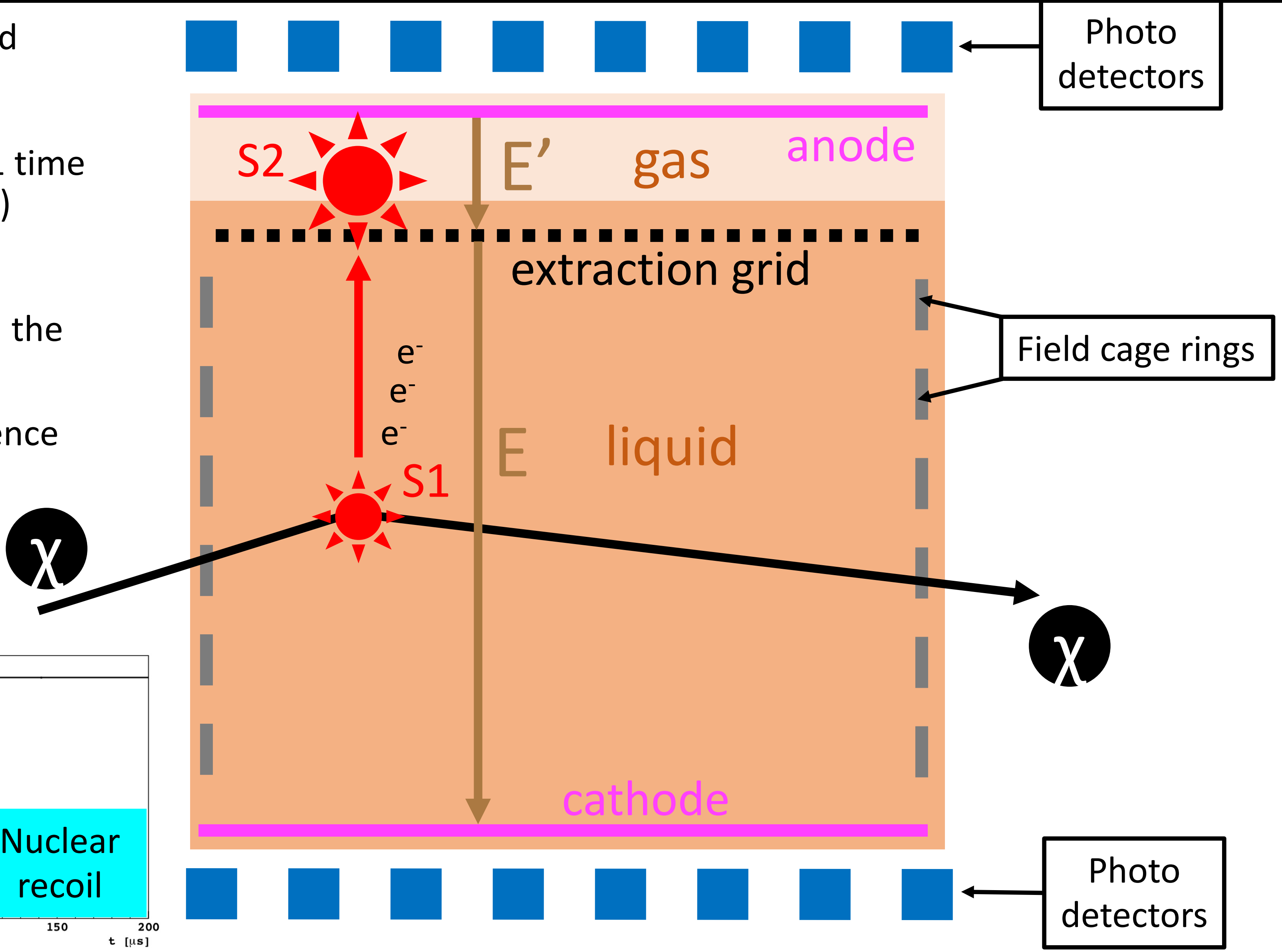
- Higher electric field across gas pocket
- Electron recoil discrimination exploits the S1 time signature – Pulse Shape Discrimination (PSD)
- Electrons drift to the extraction region
- X and Y are determined by localizing S2 with the top photo detector array
- Z is reconstructed via the arrival time difference between S2 and S1 (t_{drift})
- 3d fiducialization can be done
- Background suppression is powerful







DarkSide-20k Projections

Exposure: 200 t-y

- 20 t fiducial volume with 10 year run time
- 5 σ discovery: 2.1 x 10^{-47} cm^2 @1 TeV/c^2
- 90% C.L. exclusion: 6.3 x 10^{-48} cm^2 @1 TeV/c^2
- Sensitivity to neutrino induced coherent scattering (CEvNS): 3.2 events

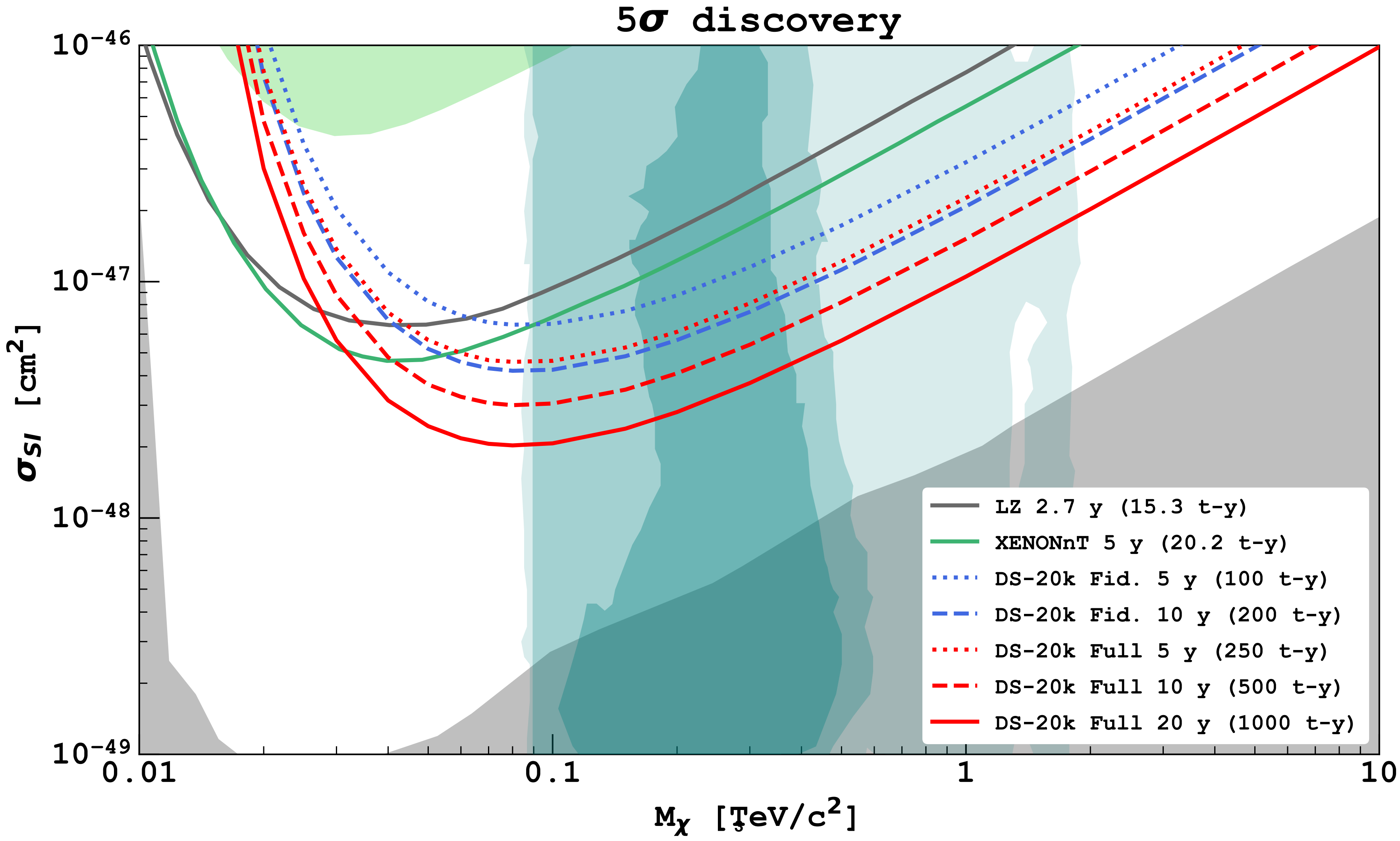
Instrumental Background

- 0.1 background events over 200 t-y in the ROI (30-200 keV$_{nr}$)

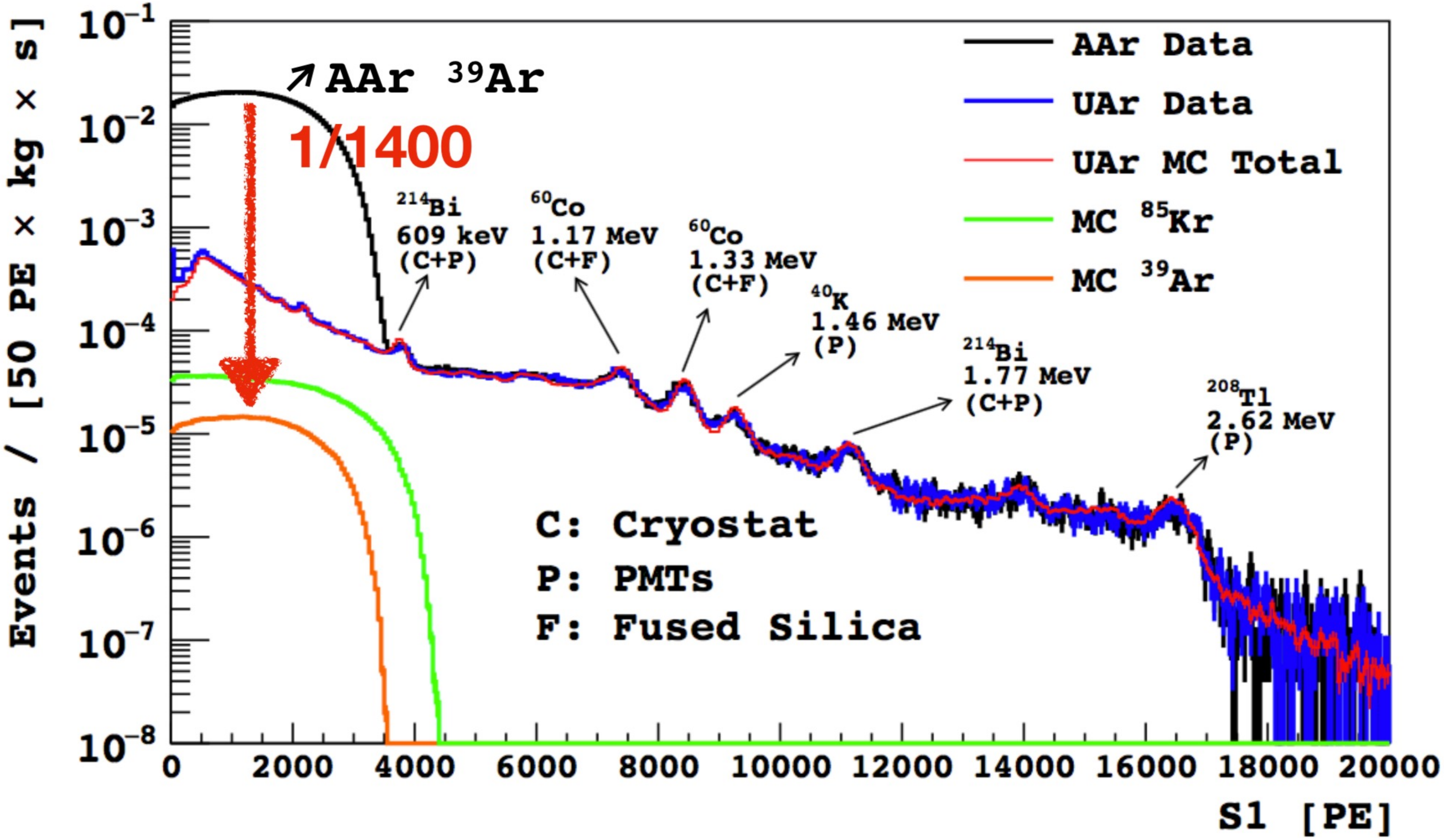
Electron Recoil Rejection

- Expect > 10^8 discrimination using PSD with argon

Spin Independent (SI) scattering



DarkSide-50 Underground Argon (UAr)

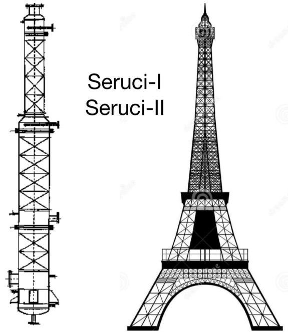


PRD, 93 (2016): 081101(R)

Industrial Scale Underground Argon (UAr)

Production – URANIA – Cortez, CO, US

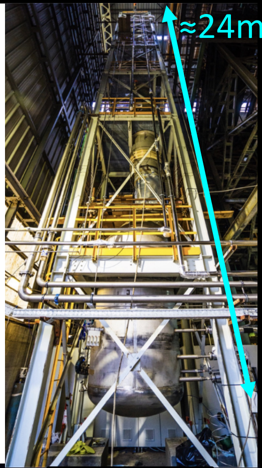
- Industrial scale extraction plant
- Extraction rate: 250-330 kg/day
- Production capability ≈ 120 t over two years for DS-20k
- UAr purity: 99.99%



Purification – ARIA – Sardinia, IT

Eur. Phys. J. C (2021) 81:359

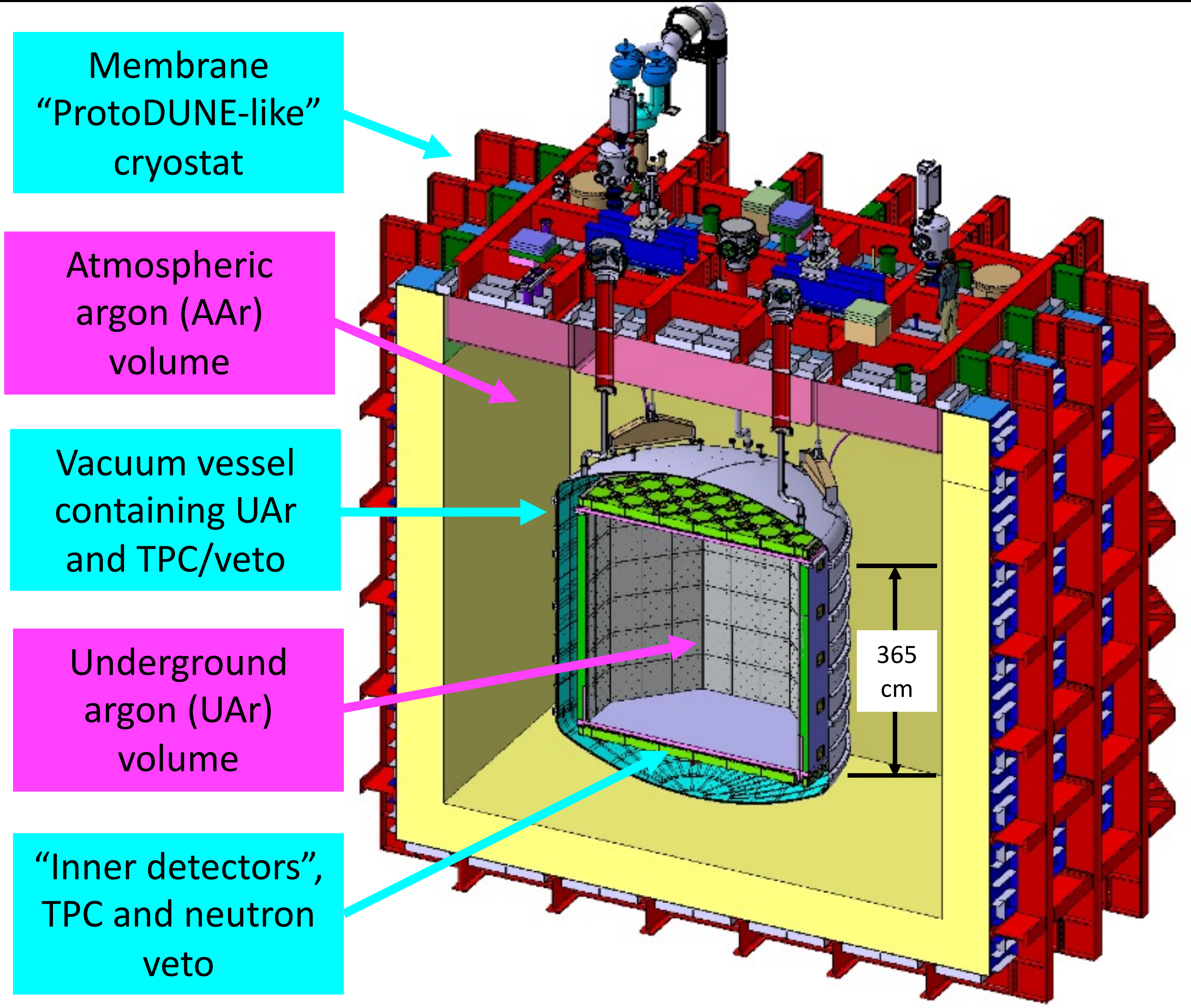
- Seruci-0 (demonstrator) tested
- 350 m cryogenic distillation column
- O(1 tonne)/day capability
- Resulting UAr purity: 99.999%



Seruci-0

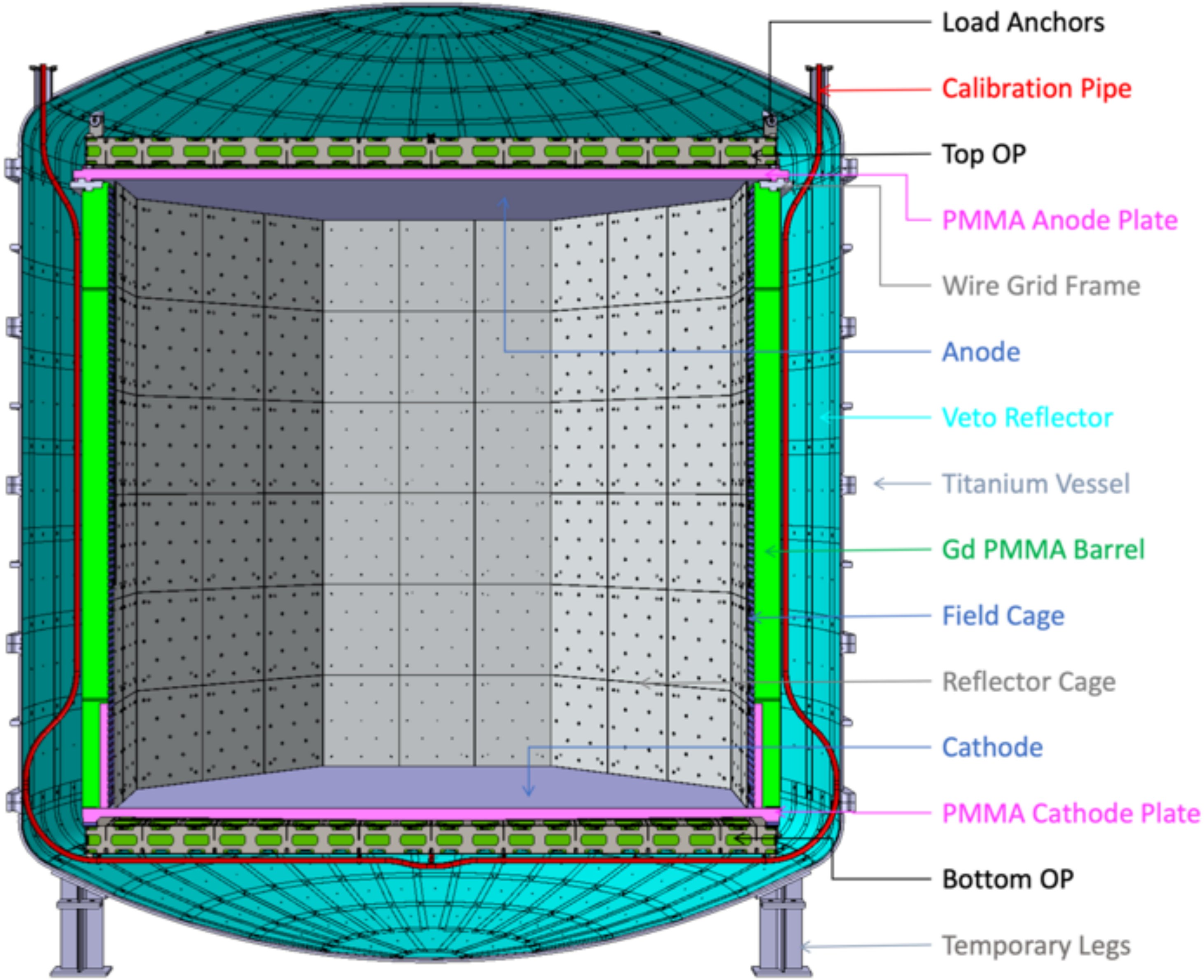
DarkSide-20k Overview

- Dual-phase liquid argon (LAr) TPC
- Fiducial volume of ≈ 20 tonnes (≈ 100 tonnes total) of underground argon (UAr), depleted in ^{39}Ar
- Active neutron veto integrated into the TPC structure via gadolinium-loaded PMMA (acrylic)
- TPC and inner veto sealed inside a stainless steel single-walled vacuum vessel containing UAr
- Sophisticated silicon photomultiplier (SiPM) based photo detection (total area ≈ 26 m^2)
- Vessel housed within an atmospheric argon (AAr) volume maintained by a membrane cryostat (ProtoDUNE-like)
- Outer veto will instrument the AAr volume
- UAr and AAr will use separate cryogenic systems
- To be deployed in Hall-C of INFN-LNGS
- Start of operations in 2026

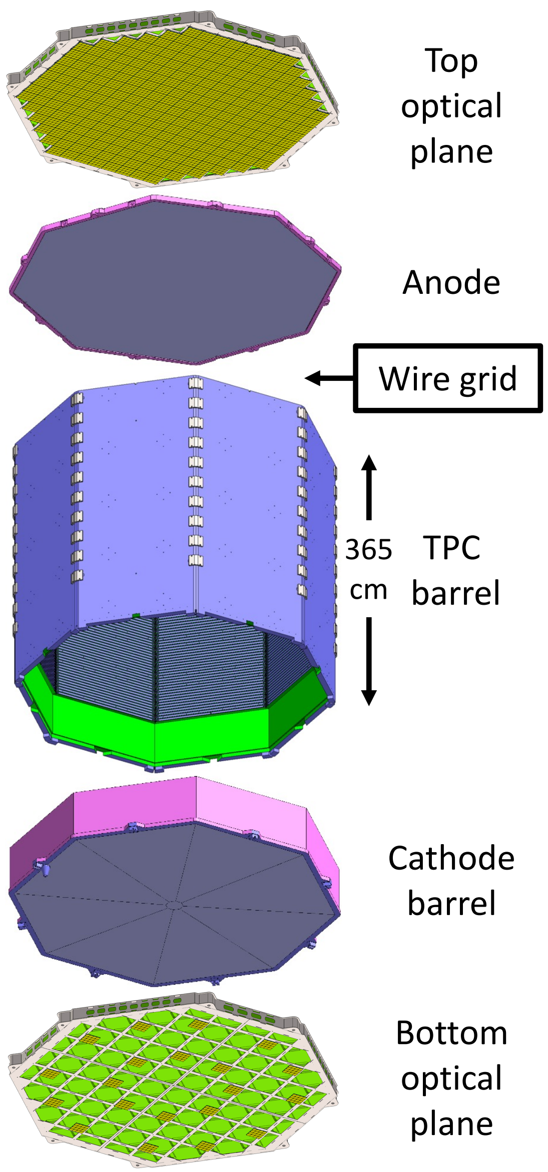


Inner Detectors Cross Section

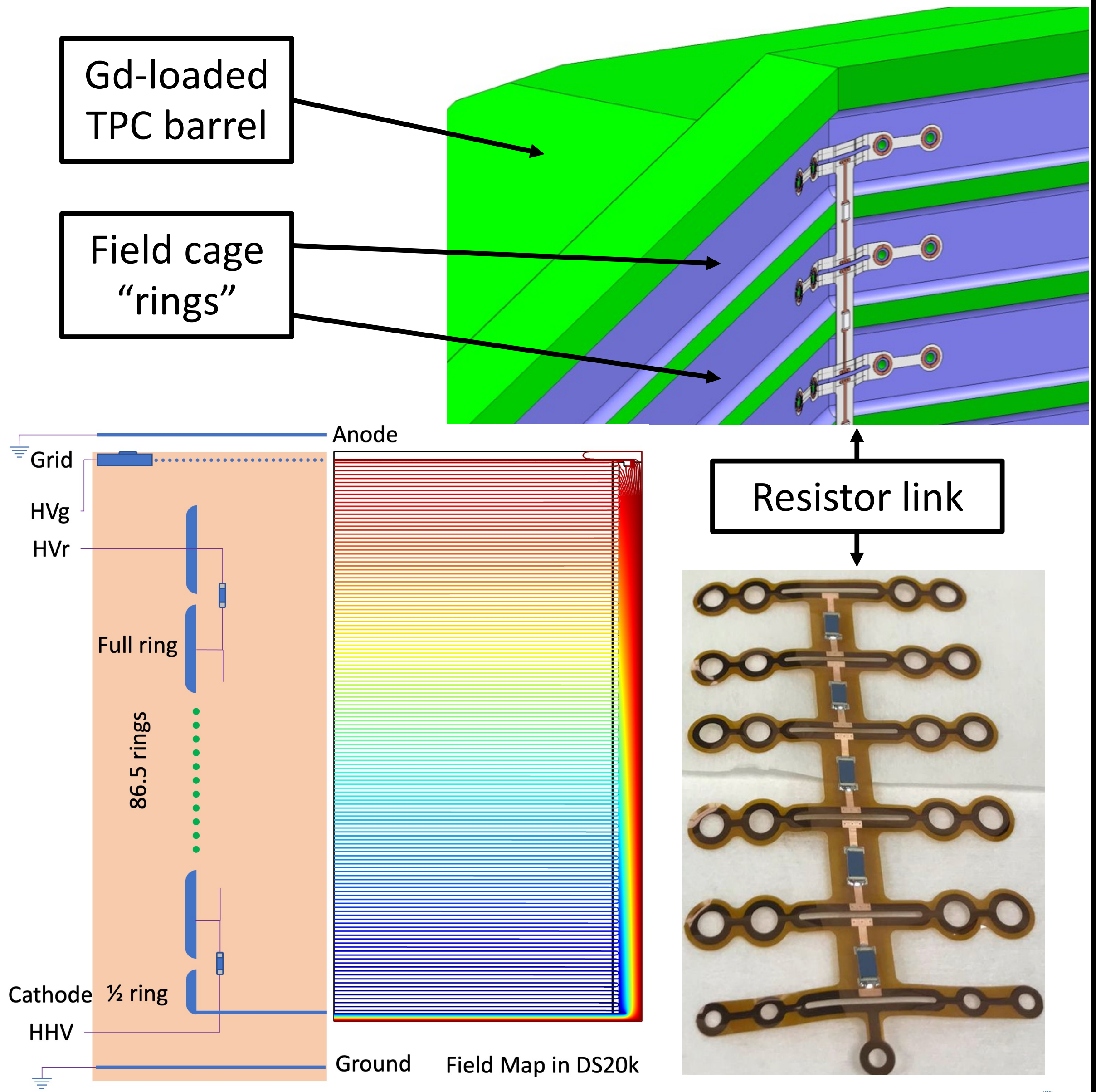
- Gd-loaded PMMA panels (green) provide the mechanical structure of the TPC
- Gadolinium provides a high cross section target for neutron capture
- Eight panels, held together with stainless steel brackets, will form the TPC “barrel”
- Reflector “cage” (gray) will be made out ESR foils mounted onto thin acrylic panels
- For the TPC volume, ESR as reflector and TPB as wavelength shifter
- Anode and cathode PMMA “windows” (pink) will be coated with Clevios™ (blue) and TPB
- Stainless steel wire grid for extraction field
- For the neutron veto volume, ESR as reflector and PEN as wavelength shifter (teal)
- SiPM-based readout planes (optical planes) will use stainless steel frames to support the readout and the Gd-loaded PMMA endcaps



Major Components and Electric Fields



- Extraction (wire) grid will be placed between the TPC barrel and anode
- Remaining electric potentials will be defined using Clevios™
- Field cage electrical connections are provided by Kapton® strips mounted with resistors
- Four redundant connections will be made to each field cage ring
- Ring geometry and coverage area optimized resulting in a highly uniform electric drift field
- The wire grid is decoupled from the resistive divider to control the electric field uniformity
- Nominal drift field of 200 V/cm (cathode operates at ≈ 73.4 kV)
- Nominal electroluminesence field of 4.2 kV/cm

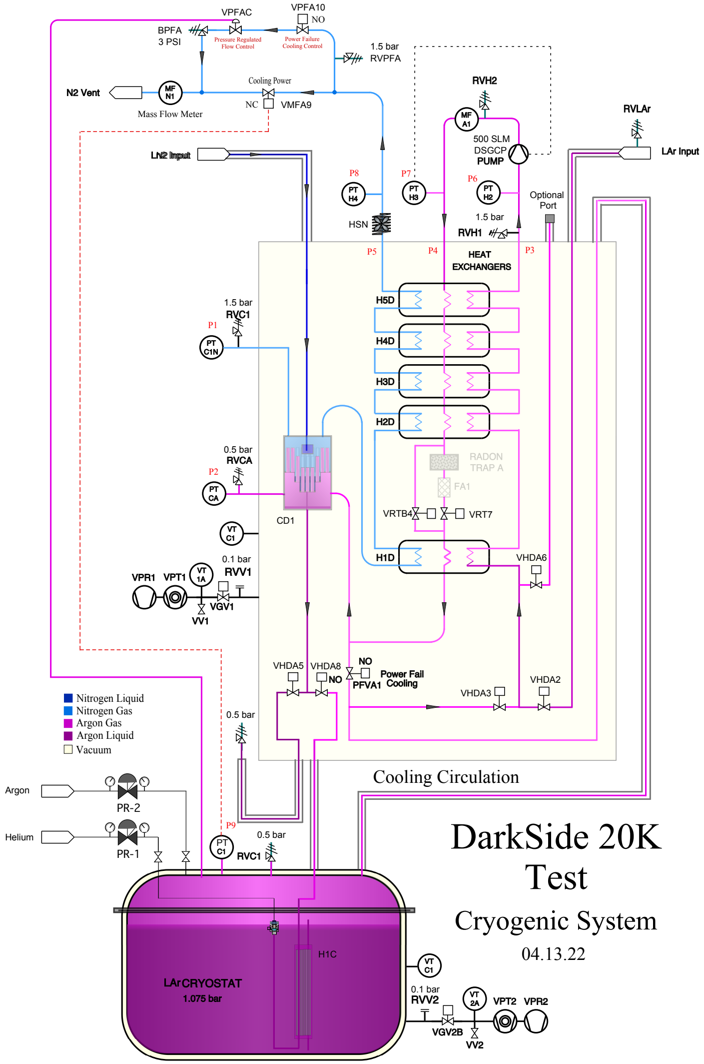


DS-20k UAr Cryogenic System Overview

- System design based on DarkSide-50 system, which operated stably for over 8 years
- Safety: cooling uses liquid nitrogen (LN_2) and has a power failure operational mode built-in
- Operating costs: sophisticated network of heat exchangers realize a highly efficient system
- Condenser uses no active controls, but is coupled to the argon gas pressure which controls cooling
- Pressure in the gas pocket must be very stable for S2 uniformity, DS-50 maintained a pressure stability of +-0.1 mbar operating at 1080 mbar
- Design accounts radon removal and argon purification, which will happen in gaseous phase
- System designed with 10 kW of cooling power to accommodate experimental design changes
- Gas pocket and photo electronics will use ≈ 2 kW
- Filling/emptying the UAr will require synchronization with the AAr system

DS-20k UAr Cryogenic System (Testbed @CERN)

- Getter and radon trap are not installed here
- Proof of concept and performance tests
- First tests performed in 2021 – 2022
- Large amount of cooling power from cold gas is recovered
- Detector circulation verification



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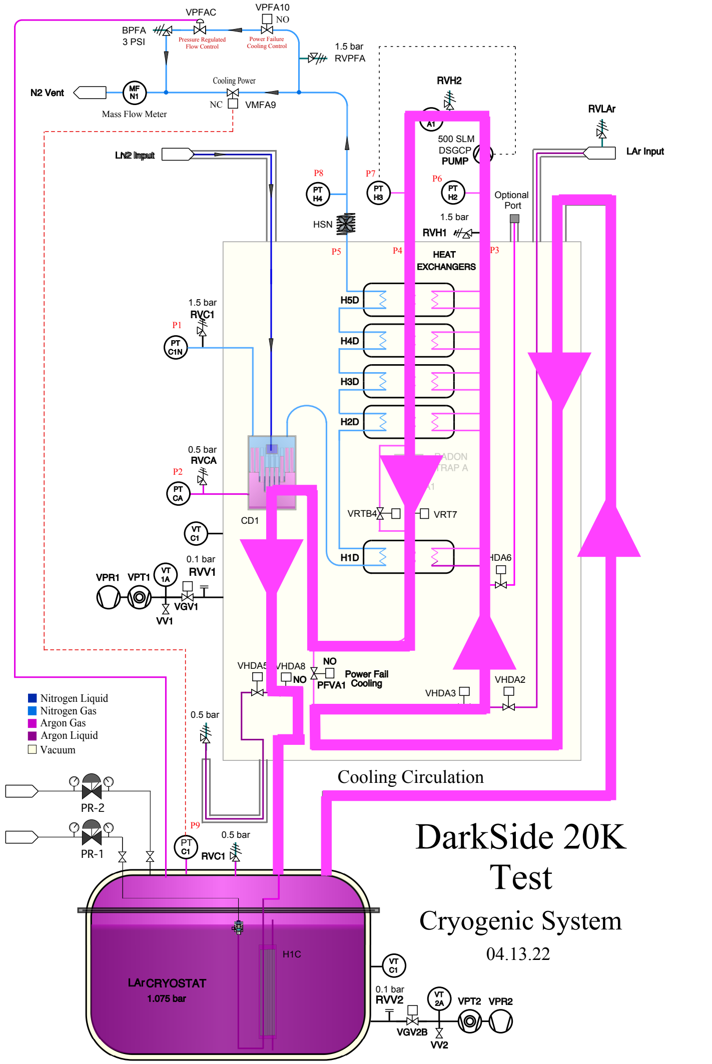
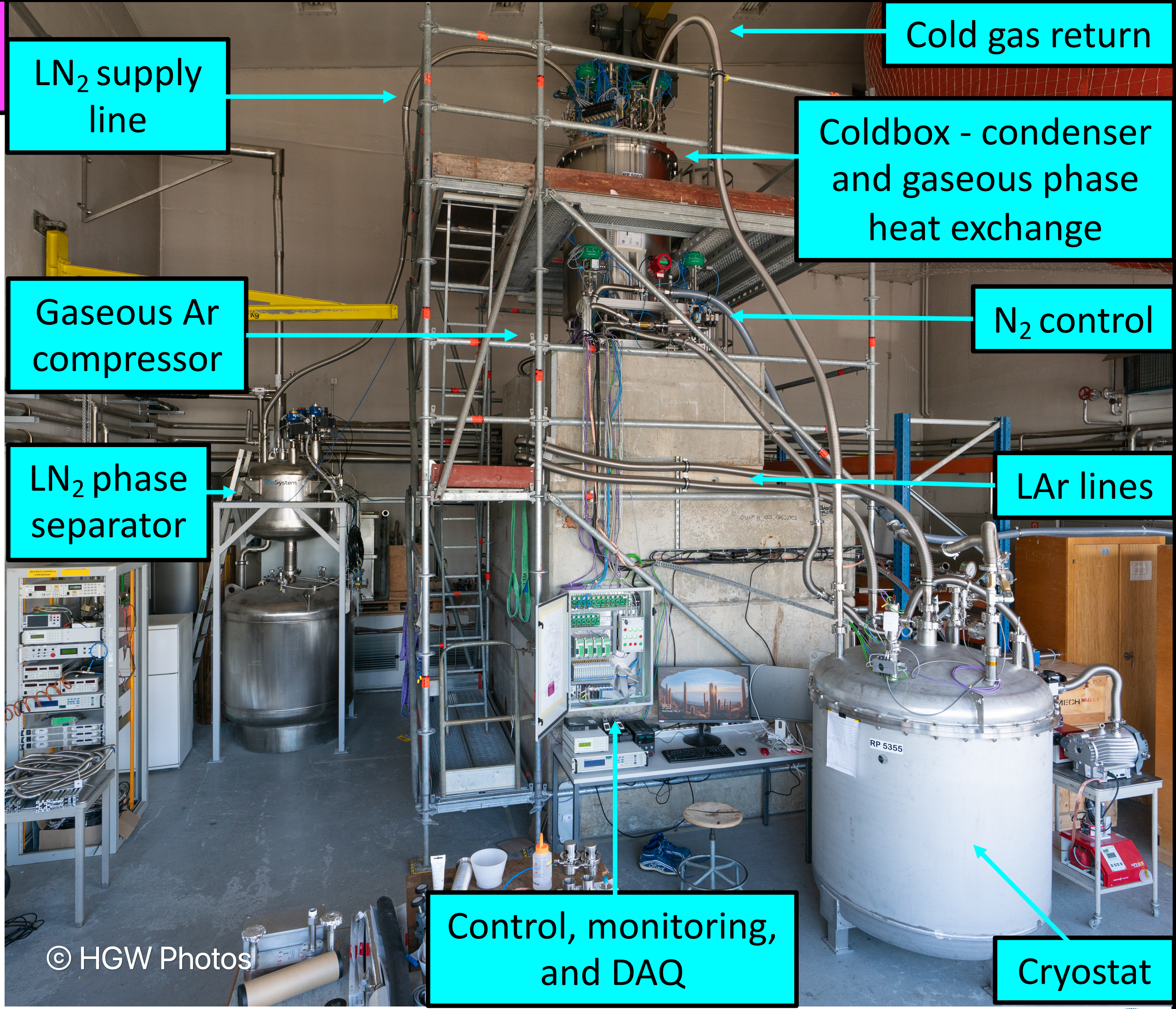
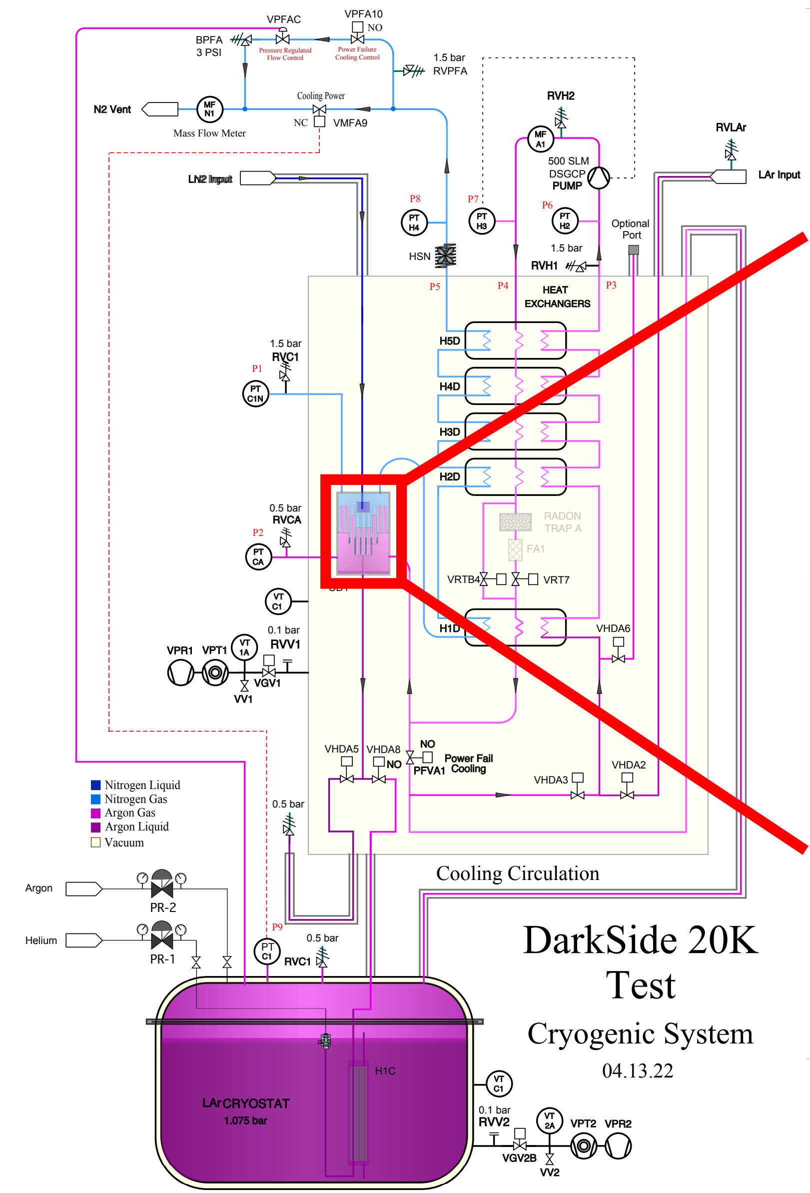
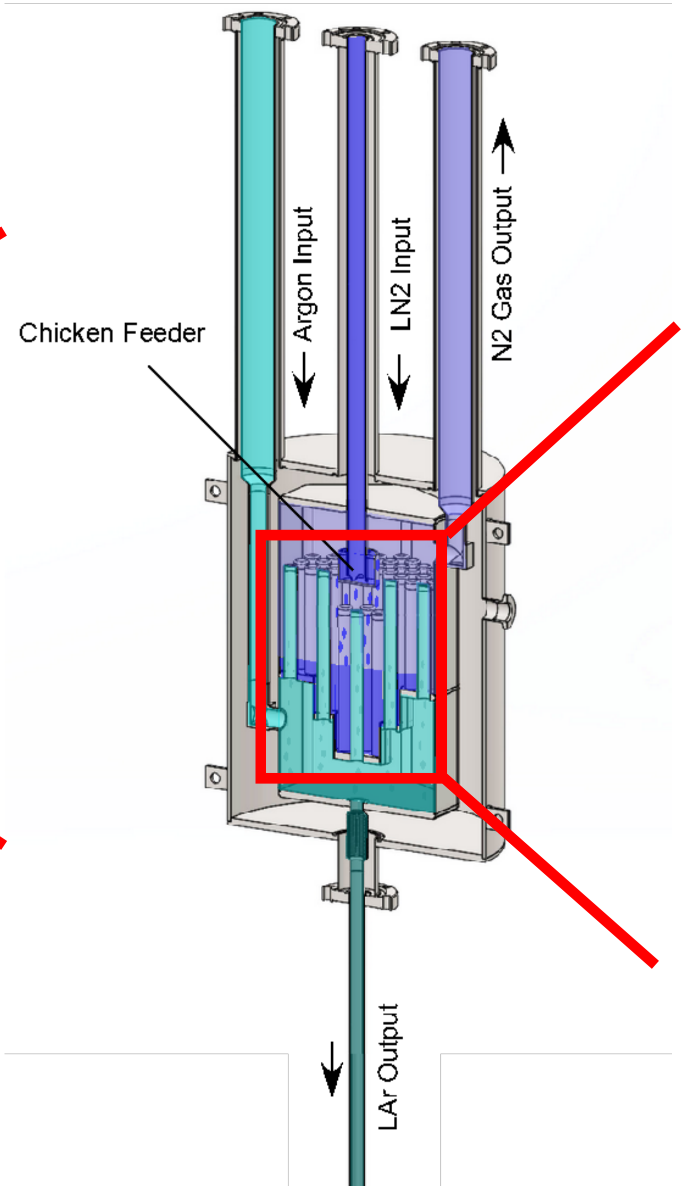
Closed argon loop with gaseous compressor highlighted





UAr Condenser – Core of the System



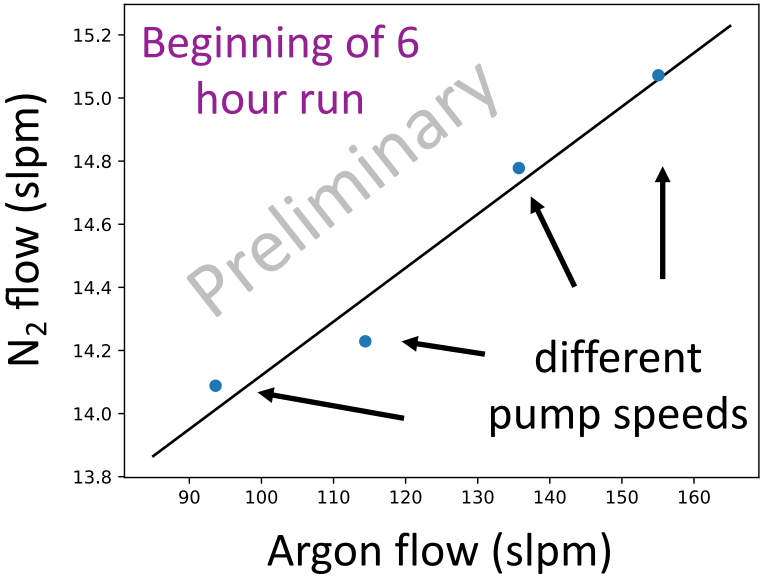


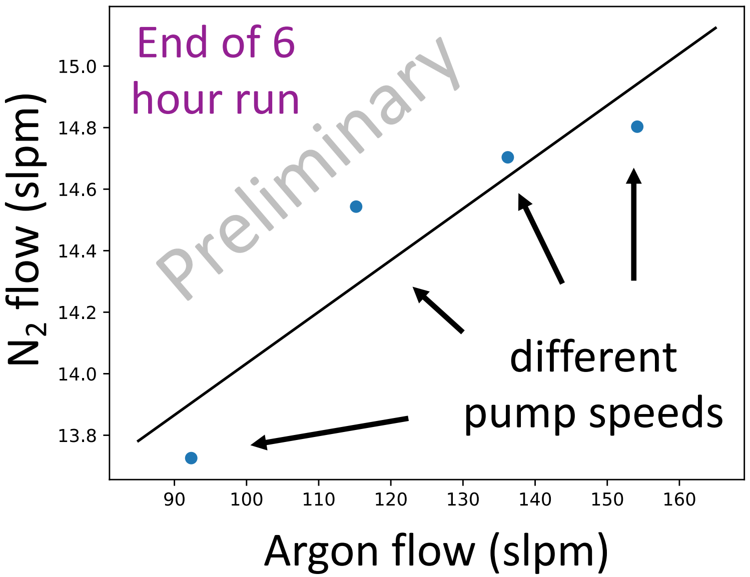
UCLA prototype – 2016-17

- No active temperature sensors or controls
- Measured 9W/inch for ½” tubing
- Gaseous N_2 flow controls the cooling power

Cooling Power Recovery Efficiency

- Fit nitrogen and argon flows over 6 hour runs at different pump speeds
- Evaluate fits and plot nitrogen vs. argon flow
- Average the values from the beginning and end of each run

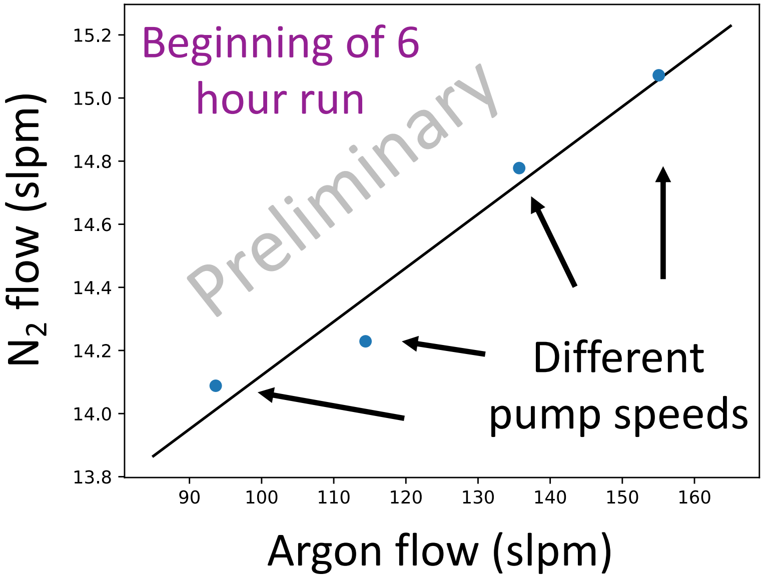


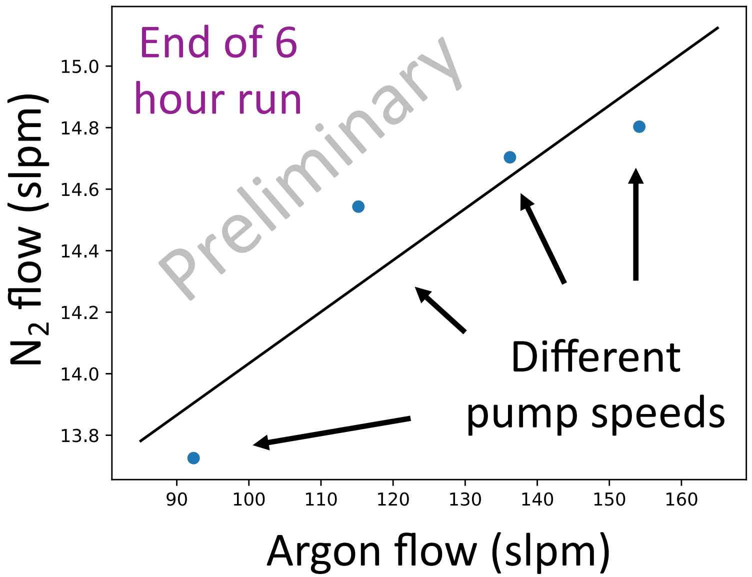


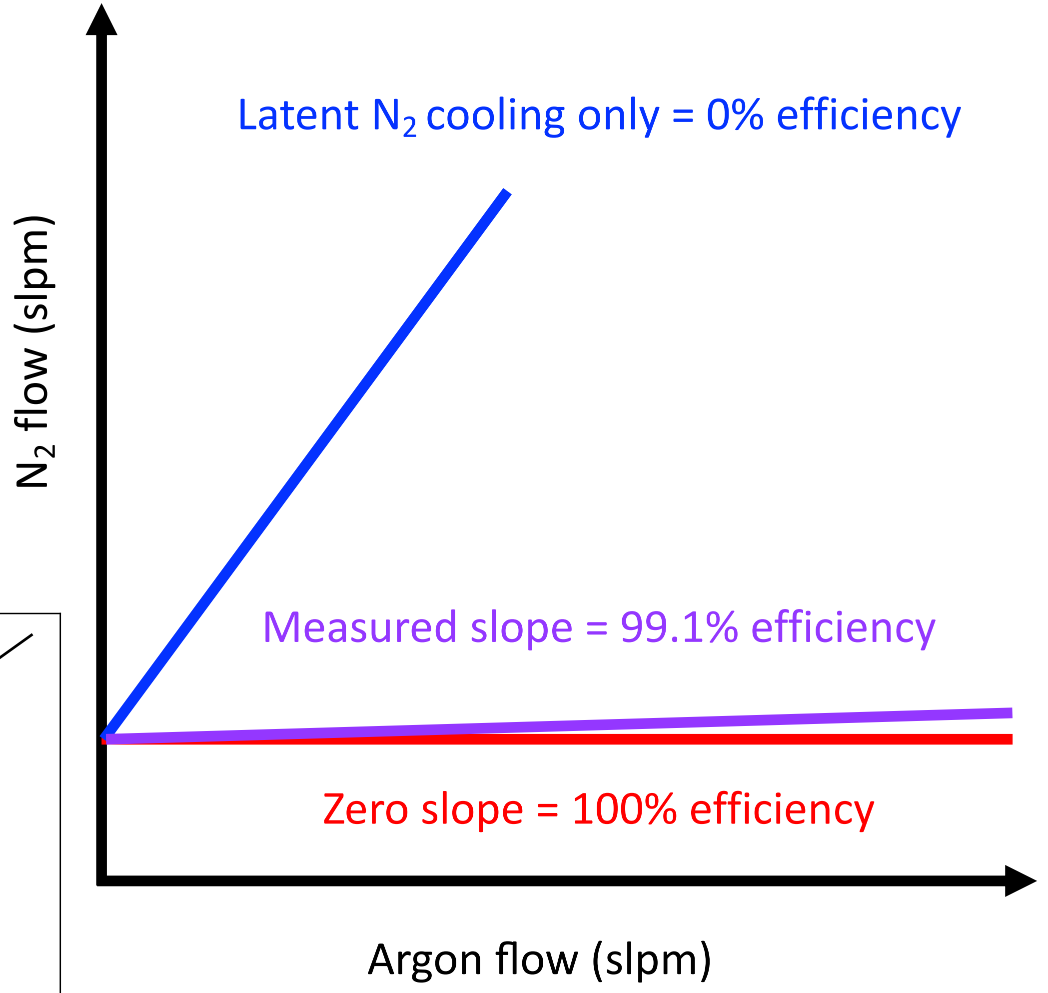
Average consumption = 0.0169 slpm N_2 / slpm Ar

Cooling Power Recovery Efficiency

- Fit nitrogen and argon flows over 6 hour runs at different pump speeds
- Evaluate fits and plot nitrogen vs. argon flow
- Average the values from the beginning and end of each run
- Define 0% efficiency as cooling argon from room temperature and condensing (using only latent heat from N_2), i.e. $m(L+c\Delta T)_{Ar} = (mL)_{N2}$
- Zero N_2 consumption is 100% efficient (zero slope here)
- Scale our measured consumption (slope) value to defined scale
- Obtain **99.1%** cooling power recovery efficiency







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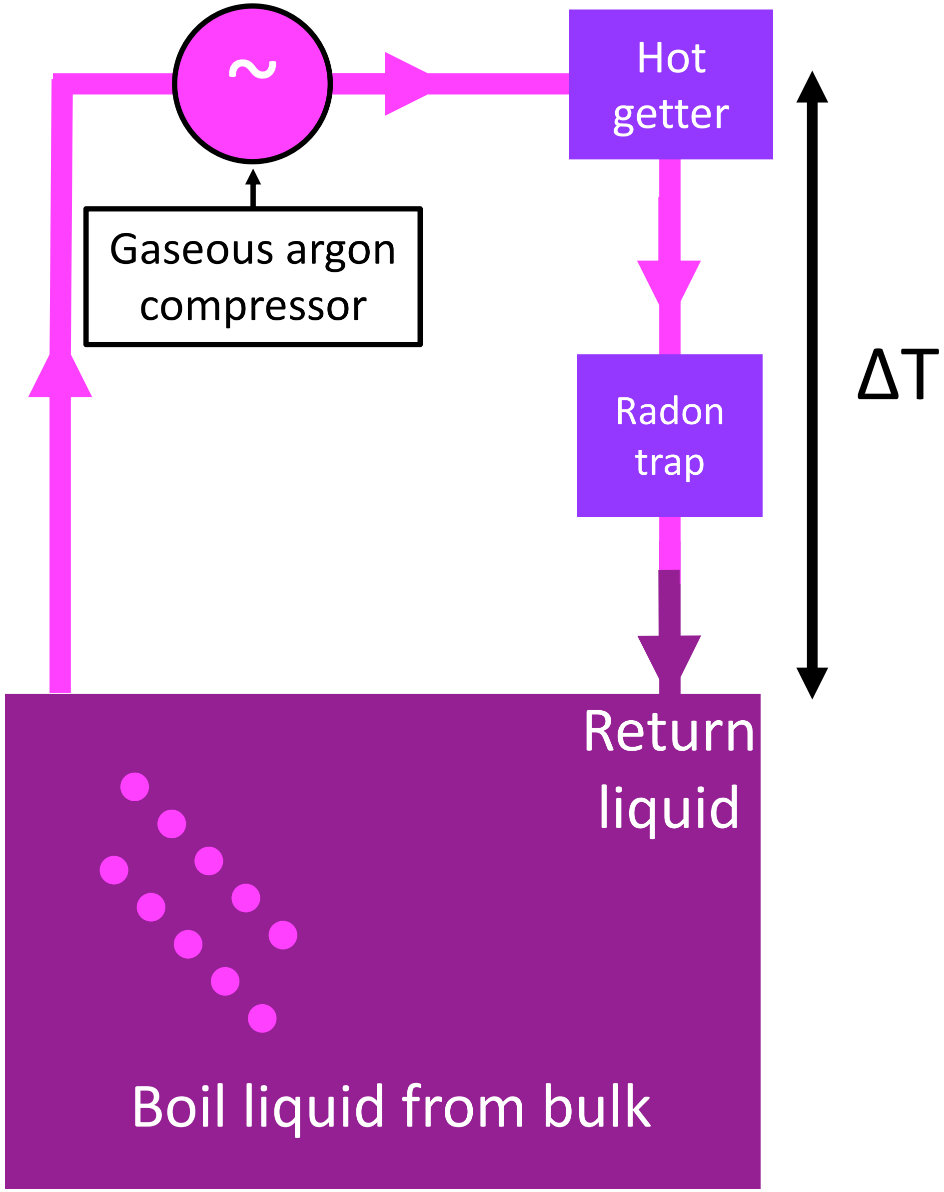
DS-20k Argon Circulation Concept



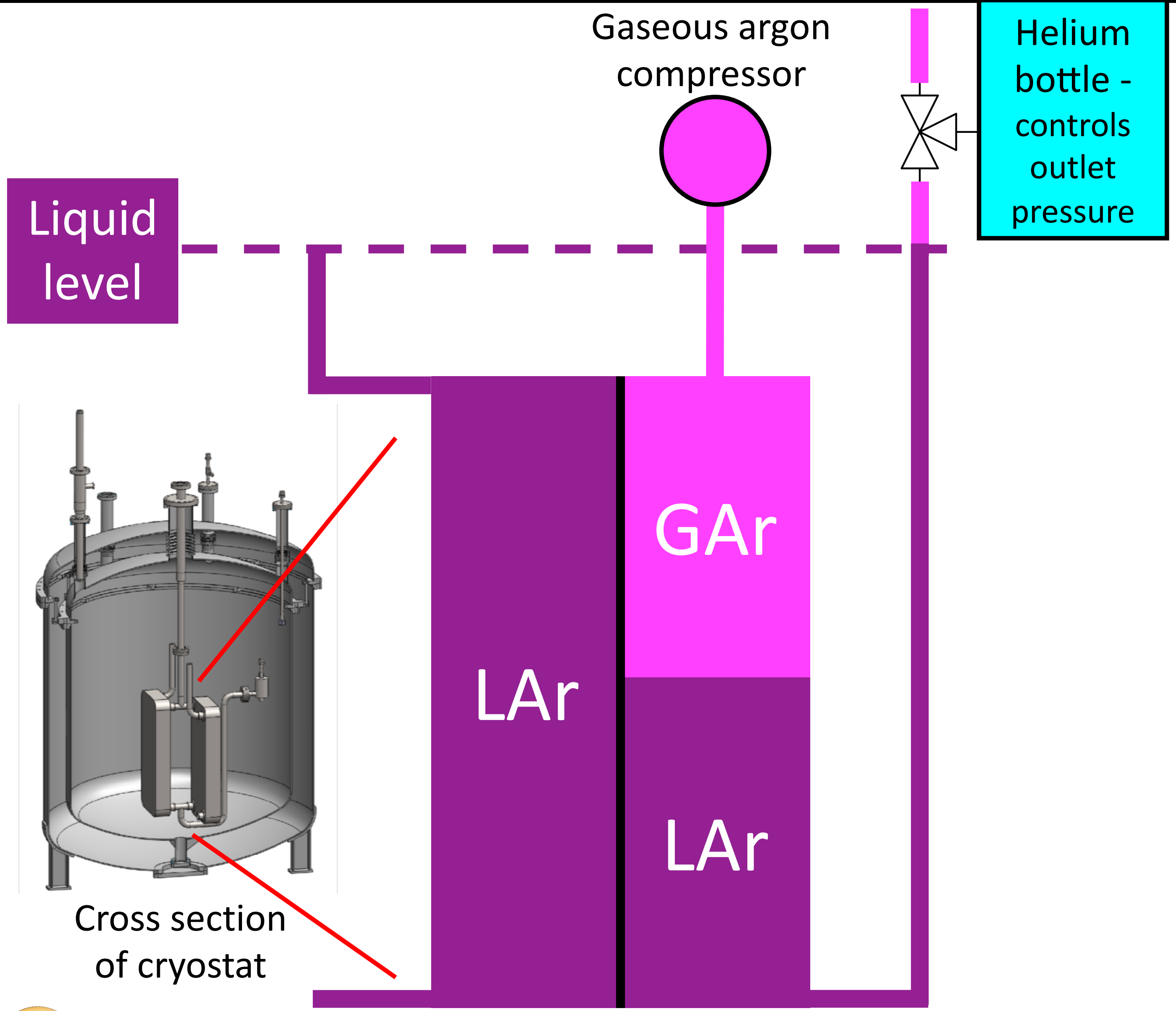
Some considerations

1. Argon purification using a hot getter requires gaseous phase
2. Radon removal from argon is near 100% efficient in gaseous phase
3. Gas pocket is required for dual-phase TPC operation
4. Gaseous pumps are reliable and easy to maintain
5. A highly efficient system requires lower liquid nitrogen consumption for a given cooling power
6. During an emergency in an underground laboratory, electrical power may be interrupted and the supply of liquid nitrogen may become limited

Strategy

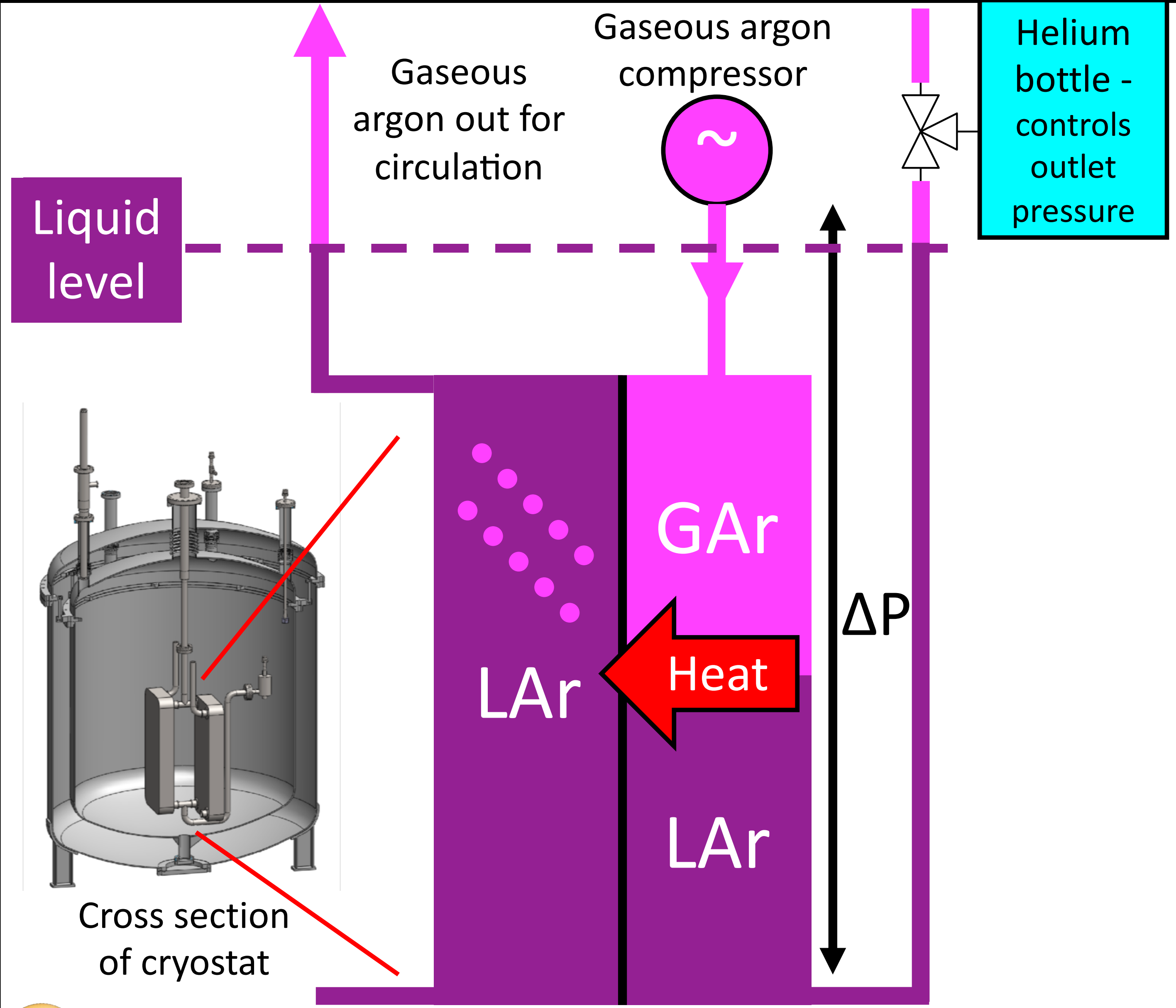
Design a safety-focused system to circulate in gaseous phase while allowing heat exchange over the entire temperature gradient from room temperature down to liquid temperature, returning the clean liquid to the bulk.

Argon Circulation Test



- One side of heat exchanger (inside cryostat) is filled with liquid from the bulk
- Argon outlet (liquid/gas mixture from compressor) is routed through other side of heat exchanger

Argon Circulation Test



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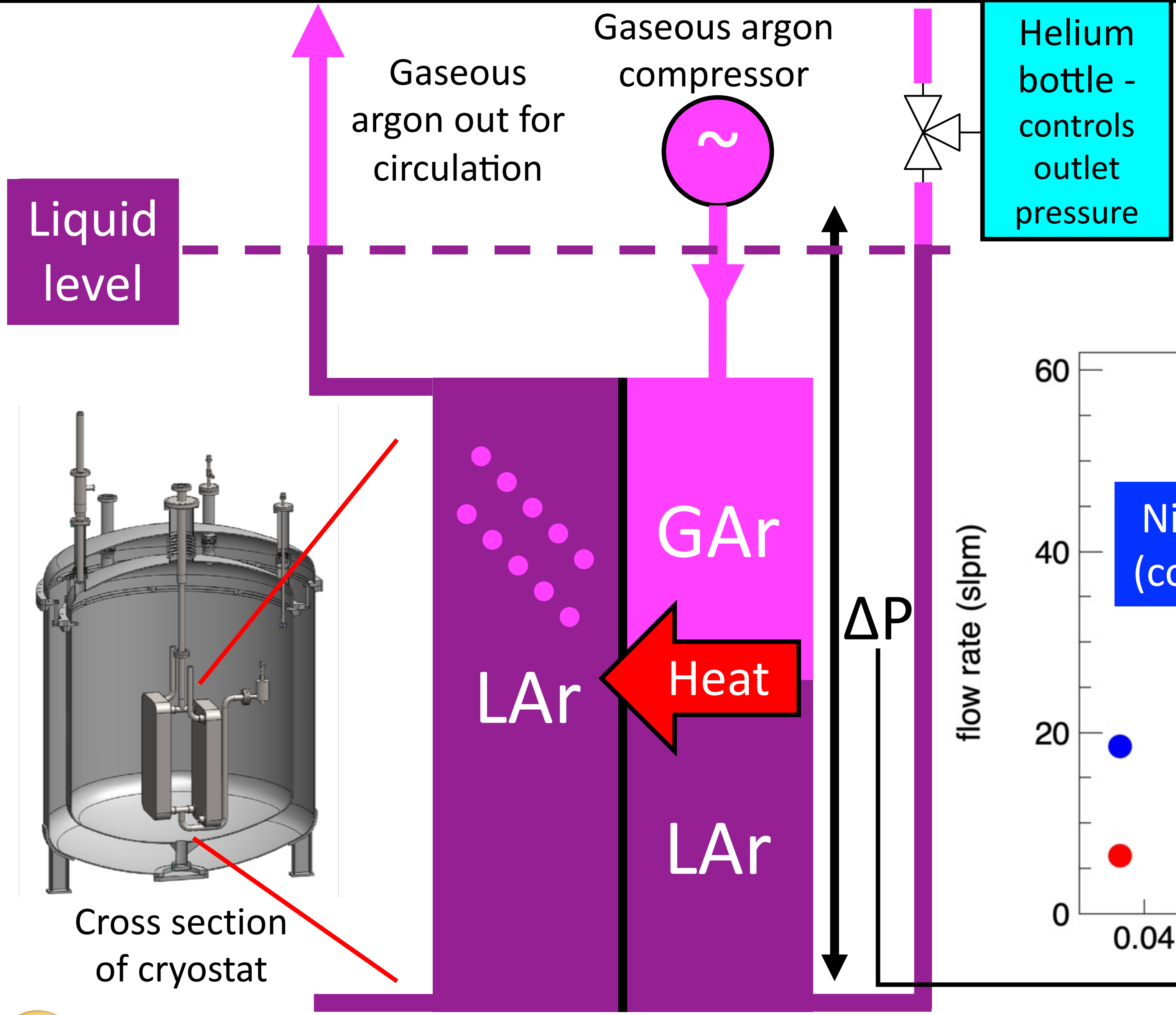
- Pressure difference turns liquid/gas mixture into liquid
- Heat is produced, boiling the liquid from the bulk

Argon Circulation Test Results



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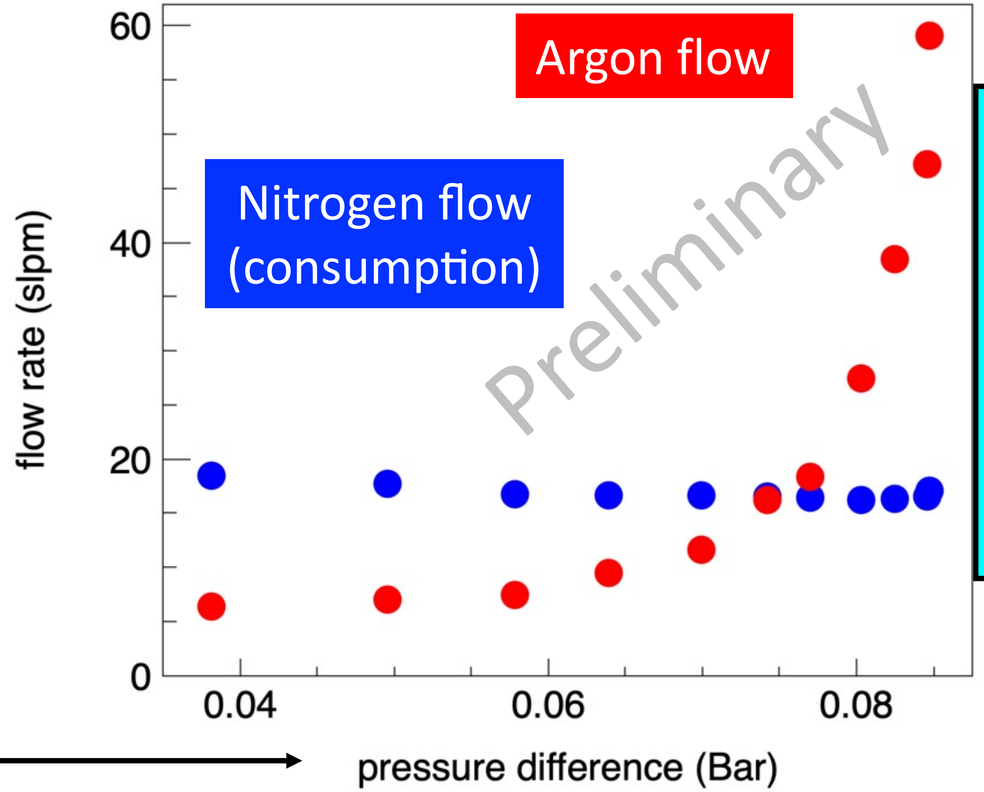

Up to 60 slpm of argon is being circulated and recondensed while the nitrogen consumption remains constant

Summary

- DarkSide-20k: dual-phase time projection chamber (TPC)
- Low-radioactivity argon sourced from underground as target material
  - ≈ 20 t fiducial volume; ≈ 50 t TPC active volume; ≈ 100 t total volume
- Gd-loaded PMMA panels will form the TPC mechanical structure (barrel)
  - PMMA (acrylic) = neutron moderator
  - Gadolinium (Gd) = neutron target material
- TPC design is in an advanced stage and assembly procedure is being finalized
- Underground Argon (UAr) cryogenic system has been successfully tested and is being relocated to INFN-LNGS
- Mechanical mockup testing scheduled to take place at INFN-LNGS starting this year
  - Mechanical design integrity
  - High voltage
  - Gas pocket formation
  - Further cryogenic system operation will be involved

Other Liquid Argon Talks at IDM 2022

- Neutron tagging with gadolinium-loaded PMMA – A. Caminata
  - Monday, July 18 – Session 1C, 14:40, EI9
- Overview and recent results from the DEAP-3600 experiment – A. Erlandson
  - Tuesday, July 19 – Session 2A, 15:50, EI7
- Search for low mass WIMP dark matter with DarkSide-50 – M. Kimura
  - Tuesday, July 19 – Session 2A, 18:00, EI7
- Constraints on dark matter-nucleon effective couplings with DEAP-3600 and prospects for the next campaign – V. Fortes
  - Tuesday, July 19 – Session 2A, 18:20, EI7